THE

ONTARIO WATER RESOURCES

COMMISSION

AID FOR LAKES PROGRAM

(Artificially Induced Destratification)

Progress Report on the Destratification of Buchanan Lake

DECEMBER, 1971

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Preface

The OWRC is charged with the responsibility of managing the water resources in Ontario in the best interests of the people and the environment. There has been heavy emphasis on pollution control via waste treatment and improved quality of all discharges to watercourses.

In addition to more sophisticated waste treatment and disposal, it has become apparent in recent years that other techniques will be required in order to manage lakes for optimum benefits. While elimination of all waste inputs to a lake should maintain water quality, this ideal situation has not always been achieved in the past and for many lakes in urban and agricultural areas this objective seems far away.

Artificial destratification and harvesting of aquatic weeds have been under consideration for some time by the OWRC as possible lake management techniques whereby the quality of lake water can be enhanced. It is not proposed that either technique be used in lieu of control of waste discharges but rather in concert with waste control or in cases where wastes are either not controllable or are not the cause of a particular water use impairment.

In June, 1971, Dr. E.C. Steele requested help in setting up equipment to destratify Buchanan Lake. The lake is no longer supporting a trout fishery which apparently existed in the 1930's and 1940's and extensive anoxic conditions seem to be the cause.

A preliminary survey on June 24 confirmed the anoxic condition but no sources of pollution were observed. The lake had many features required for a destratification experiment and these combined with the cooperativeness of Dr. Steele supported a decision to go ahead with the project.

Equipment was ordered, built and delivered within a few days, power was installed to the lake shore at Dr. E.C. Steele's cost, and the compressor was put in operation on July 14 only three weeks after we first heard of the lake. The work has been dependent on the generosity and cooperation of many people within the OWRC and the Department of Lands and Forests and I sincerely thank all who have played a part. Thanks is extended particularly to Mr. C.E. Simpson and Mr. Carl Schenk who branches bore the great majority of the cost and work load.

T.G.B.

Summary and Conclusions

The complete destratification of a lake using a small volume of air discharged as small bubbles in the deepest part is shown to be physically and economically feasible.

Artificial destratification resulted in improved water quality with respect to hydrogen sulphide, dissolved oxygen, carbon dioxide, ammonia nitrogen, total phosphorus and iron.

Algal crops measured as chlorophyll a and areal standard units increased by five to six times the pre-destratification values over a period of ten weeks. Corresponding Secchi disk readings decreased from ten to six feet. Total phosphorus concentrations in the surface water remained between 0.014 and 0.020 mgm per liter throughout the study period. Chemical results indicated a constant production of ammonia and carbon dioxide from the sediments. It is believed that these nutrients supported large numbers of algae even though the total phosphorus did not reach concentrations normally associated with so much algae.

Zooplankton populations underwent a four fold increase in number following destratification with the biggest changes in the deep water.

There were marginal improvements in bottom fauna and sediment chemistry and it is hoped that continued mixing will produce large enough changes to support firm conclusions.

Increased oxygen and food supply (phytoplankton and zooplankton) in the bottom waters have established a potential habitat for relatively cold water species of fish. Limited netting of the residual population in September, 1971, indicated the trout were thriving. Trout are to be stocked in 1972 followed by detailed studies of their survival and growth.

Water velocity measurements generated by the rising bubbles were up to 30 cm/sec and the flow of water was estimated to be between 25 and 50 cubic meters/sec. This gave a turnover time of only 4.8 hours. Up to 20% of the horsepower rating of the compressor was converted to kinetic energy in the water based on the velocity measurements. The actual conversion may have been higher since it is not known whether the compressor was actually working at its rated horsepower.

There have been many positive benefits already from artificially induced destratification in Buchanan Lake but some questions remain, particularly with regard to algae growth. Continuation of this type of study is required in order to fully understand the physical, chemical and biological consequences to ensure proper use of the technique as a water management tool.

DESTRATIFICATION OF BUCHANAN LAKE

Introduction

Forced circulation has been used to eliminate anoxic bottom waters in thermally stratified lakes and reservoirs in numerous cases going back to at least 1952 (1). The most common purpose has been to improve water quality in reservoirs used for drinking water supplies although Halsey (2) used the technique to provide oxygen in a meromictic lake to prevent winter kill of fish, and Hooper's (1) experiment was designed to grow more algae by injecting nutrient rich bottom water into the epilimnion.

The American Water Works Association's Committee on Quality Control in Reservoirs (3), has reviewed 29 cases of destratification going back eleven years and found 25 are regarded as successful and only one unsuccessful with the other three not having drawn any conclusions yet. The main water quality improvements have been elimination of iron, manganese, ammonia and sulphides which are all unacceptable in drinking water supplies.

It has been largely a secondary observation that algal numbers usually decreased following destratification (4). Only three

of the 29 cases examined by the A.W.W.A. Committee reported increases in algae. This observation along with the greater potential fish habitat resulting from destratification has attracted the attention of people involved in eutrophication control (5). Kezar Lake in New Hampshire (6), is one of the few reported cases where destratification was carried out solely to improve aesthetics in a eutrophic lake. Water clarity increased from less than one to more than two feet, algae decreased and residents around the lake were much happier. Nutrient control had not yet been put in operation at a sewage treatment plant discharging to the lake and the lake remained productive during the time studied.

The effects of destratification on water quality are well understood but the reasons for changes in algae population and ultimate effects on the fishery are not well documented and use of this technique as a lake management tool is still highly experimental.

Principle of Operation

When lakes become thermally stratified and the water exchange between the surface and the more dense bottom water virtually ceases, the concentrations of inorganic nitrogen, phosphorus, carbon dioxide and other chemicals increase in the bottom water. This is due to accumulation of plant and animal debris settling from the surface and to release from sediments by decomposition. Since the oxygen supply is essentially cut off by stratification, the bacteria can reduce the concentration to zero and the resulting chemical reducing reactions

release additional material to the water from the sediments. The most important reaction is insoluble iron III going to the soluble iron II form with the resulting release of adsorbed phosphorus. Manganese is released in a similar way and ammonia and hydrogen sulphide buildup from decomposition of organic matter and reduction of nitrate and sulphate respectively. All of these processes are quite normal and take place in virgin lakes and it seems that the effect of waste inputs is largely of magnitude not of kind.

During spring and fall the lakes in this latitude become mixed due to surface temperature changes and wind action. The nutrients in the bottom water, which are often ten times or more than the surface concentration, become available to the illuminated surface water and the classical spring and fall algae pulses follow.

The idea behind artificial destratification (forced circulation or mixing) is to keep the bottom water from becoming anoxic giving rise to three main benefits: improved water quality for drinking; prevention of phosphorus and other plant nutrients recycling from sediments; improved food supply (bottom fauna) and habitat for fish. Mortimer (7) has concluded that oxic sediments do not exert any significant effect on the overlying water.

If the bottom waters become anoxic before destratification is started then there is a risk of causing increased algae just as during ordinary spring and fall overturn. Early experiments such as Hoopers were designed to do this since the objective was increased primary productivity and indeed he succeeded in getting an eight to tenfold increase in algae volume. On the other hand, if the water is kept constantly mixed

so that anoxic conditions never develop there is a net removal of phosphorus from the water although apparently nobody has directly linked this effect to any of the observed decreases in algae.

Engineering

A variety of methods have been proposed and used to destratify lakes including mechanical pumping (8), selective withdrawal from dams (9) and diffused air systems (5). Diffused air has generally been the most successful and cheapest so only these systems have been considered in this report. Oxygen is not added to the water directly from the bubbles to any great extent. The induced currents provide oxygen from the surface of the lake.

The three basic design questions are: how much air to use, how to apply it, and how long to apply it? All three questions have been answered mainly by trial and error. A review of eleven successful experiments and one failure did not reveal many common design features.

How Much Air? The relative volumes of lake water and air are conveniently expressed as the ratio of water in millions of cubic feet to air in cubic feet per minute, W/A. Successful experiments have used W/A ratios from 0.09 (4) to 40 (10) but one experiment at a ratio of 21 (11) didn't give good mixing and the 40 case barely generated enough oxygen in the bottom water to prevent reduction reactions. Trials with a small pump in a large body of water suggest that the maximum practical ratio is about 19 (5).

The most obvious difference among the experiments is the time of turnover (time required to move a volume of water equal to the lake volume) which is estimated in some cases and ranges from more than once per day (4) to less than once per week (10).

In general, for a weekly turnover time the W/A ratio needed is from 2 to 5. That is, one cubic foot of air per minute (cfm) for every 2 to 5 million cubic feet of water. A great variety of reasonably priced compressors are available in the 10 cfm range so for lakes up to 50 million cubic feet (1200 acre ft) selection of a pump isn't a critical problem. It is only when large volumes of water are considered that the maximum W/A ratio becomes critical from a cost standpoint.

How to Apply The Air? The diffusers used range from 40 to 2300 feet long, hole sizes from 2/64" to 9/64" and air volumes per hole from 0.14 to 6.3 cfm. Hole spacings vary from 6" to several feet and configurations include straight lines, circles and X shapes. The essential features seem to be small holes spread over a reasonably large area or length and placed in the deepest part of the lake.

How Long to Apply the Air? Few people have been interested in allowing anoxic conditions to be re-established so in most cases pumps have been run constantly or for part of each day (3). From a cost consideration it is better to use a small pump running constantly than to use a large pump for part time operation. Pump failures (including one in Buchanan Lake) indicate a rapid decline in water quality conditions if mixing is stopped, so continuous operation does appear to be a prime objective.

The kinetic energy required to move the appropriate water masses sets the ultimate limit of energy applied via air volume and pressure. This is discussed below for Buchanan Lake.

The A.W.W.A. Committee give an excellent summary of capital and operating costs and power for the 29 actual cases they examined (3), but they observed a wide variation in all three parameters. For example, the horse power applied per unit volume of water varied by a factor of 10 for reservoirs of the same size.

Buchanan Lake

Buchanan Lake has a surface area of 21.25 acres, a volume of 15 million cubic feet and is located in Haliburton County about 12 miles north east of Dorset. It is surrounded by mixed forest with rocky shores with no inlet streams and an outfall of only 0.2 c.f.s. There is one cottage which has been in constant use for one year. Figure I is a contour map showing the two chemical sampling stations, six bottom fauna stations, sediment sampling points and location of the diffuser.

The lake is alleged to have had an excellent speckled trout population in the 1930's and 1940's which apparently declined in the 1950's. All fish were poisoned in 1960 and the lake was stocked with trout in 1962, '63, '64, '65, '68 and '71 but they did not thrive.

Extensive anoxic conditions develop in the summer with low oxygen to within 15 feet of the surface. The owner, Dr. E.C. Steele, requested assistance in trying destratification to restore oxygen to the bottom waters with the hope of sufficiently satisfying the oxygen

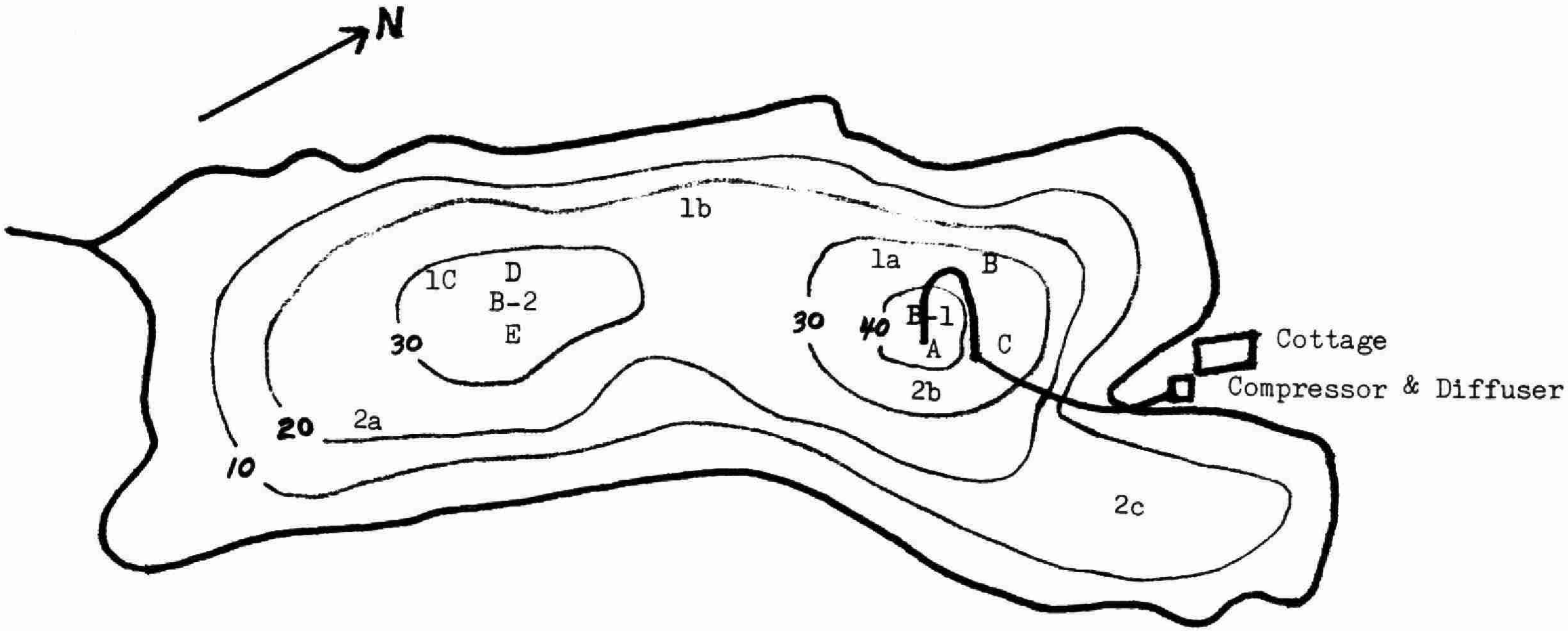


Figure I Buchanan Lake

Depth contours are in feet

B-1, B-2 Main Sampling points

A B C D E Sediment sampling points

1a, 1b, 1c, 2a, 2b, 2c, Bottom Fauna Sampling Points

demand that the normal extent of anoxic conditions would be less when destratification is finally stopped. The OWRC agreed to help on a cost shared basis and the experiment was started on July 14. The Department of Lands and Forests, Dorset, have assisted with manpower and equipment and a study of the present fish population. The experiment affords an opportunity to fully study the limnological effect of destratification in an oligotrophic lake without the added complications of large current and historical waste inputs.

Seven limnological details are being studied: water chemistry, sediment chemistry, bottom fauna, water currents, fish populations, phytoplankton and zooplankton.

Destratification Equipment

A 10 cubic foot per minute good quality compressor with a 2 H.P. 110 V electric motor was connected directly to the air line with an attached safety valve set at 75 p.s.i. and a by pass valve. The air line is 3/4" flexible polyethylene pipe 300 feet long which connects to the diffuser. The diffuser is 100 feet long with thirty one 1/32" holes drilled over the first 90 feet and six 1/16" holes drilled over the final 10 feet. When in operation air bubbles rise from the full length with as many as thirty separate bubble streams visible at the surface. It was placed in a straight line for six weeks but when the deep hole failed to fully mix it was moved to a U-shape with the far end in the 44 foot deep hole.

The capital cost was just under $800.00.

The compressor ran constantly for 10 weeks (July 14 to Sept. 23) with one four day stop when the air line developed a leak at the connection. (Sept. 5 to 9). It was operated again from October 14 to 28.

Sampling Program

Water chemistry, phytoplankton and chlorophyll a samples were collected each week at two locations from the surface and at five foot depth intervals. Surface samples for chemistry and phytoplankton were collected daily during the first week. Zooplankton samples were collected at 5 foot intervals at the deepest station on 11 dates from July to November. A partial chemical and phytoplankton sampling was carried out three weeks before starting destratification.

Temperature, dissolved oxygen, and carbon dioxide profiles were determined at both stations each week.

Sediment samples were collected four times for chemical analysis and three times for bottom fauna evaluation.

This report covers the period June 24 to November 4 although sampling is continuing on through the winter.

Vertical water currents were measured around the diffuser once and gill nets were set once to determine what kinds of fish were present and their physical condition.

RESULTS AND DISCUSSIONS

Water Chemistry

Water samples were analysed in the laboratory for total Kjeldahl nitrogen, ammonia, nitrate, nitrite, total and soluble phosphorus, iron, alkalinity, conductivity and pH using routine OWRC methods.

Temperature, dissolved oxygen (Winkler method) and free carbon dioxide (titration to pH 8.3) were determined in the field.

As had been expected, the first and most obvious effects of destratification were on the water chemistry. Almost all of the parameters measured varied with depth on July 14 and these variations were progressively reduced and eventually eliminated in all cases.

Hydrogen Sulphide Before destratification began on July 14, the 35 and 40 foot samples smelled strongly of hydrogen sulphide. When the air flow was started the smell over the boil was quite unpleasant and it was detected by several observers on the shore nearly 300 feet away. Within 24 hours the atmospheric smell had disappeared and no sulphide smell was detected from any water samples for the rest of the summer except for the 40 foot sample at Station B-1 on September 9 following the compressor failure.

Temperature Lake temperatures are determined primarily by the balance of energy gained from net solar radiation and lost by evaporation. While volumes, flows, heat loss to sediments and other factors affect each lake separately, annual and year to year variations are largely due to these two factors.

Forced circulation produces a near uniform temperature which is cooler at the surface and warmer at the bottom than during stratified conditions. Energy losses are reduced by decreased evaporation and increased by loss to the cooler sediments. Since net radiation is essentially unchanged and these two effects tend to cancel one another, the average lake temperature is not expected to change much following destratification although temperature profiles are greatly altered.

Reduced evaporation can be significant in reservoir management, particularly in warm climates. A study in California (12) showed a summer reduction of 7.4 cm and a winter increase of 3.3 cm for a net saving of 4.1 cm which is quite important in large area reservoirs.

The main biological concerns of destratification, with respect to temperature, are elimination of the cold water layer and changes in the bottom fauna due to the increased temperature. However, in lakes to be considered for destratification the low dissolved oxygen in the hypolimnion precludes fish of any kind and most desirable types of bottom fauna, consequently temperature changes are of secondary importance.

The summer temperature changes in Buchanan L. are shown in Figure C-1a and the average values for the lake are plotted in Figure C-2. It is immediately apparent that stratification was broken down although fully isothermal conditions weren't established for 9 weeks. After four weeks of mixing the water below 35 feet became stable so one end of the diffuser was moved into this hole - which accounted for less than 1% of the lake volume. Isothermal conditions would probably have occurred a

week sooner had it not been for the equipment breakdown in early September which allowed greater temperature differences to become established. The lake remained isothermal for the seven weeks following September 16 while the temperature dropped 8.7°C. Even though the compressor was turned off between September 23 and October 14, no thermal stratification resulted, presumably due to the established mixing currents being maintained by cooling and wind action.

The average lake temperatures were lower for the first two weeks of mixing which may be due to some combination of heat loss to the sediment, the cool cloudy weather in July and increased evaporation when the initially warm surface water was set in turbulent motion. Following this initial decrease the temperature followed the expected pattern of higher values in August and early September then decreased steadily to the end of the observation period.

Temperature profiles taken in nearby Millichamp Lake on July 28 and in Walkers Lake a few miles away on August 17 were used to calculate average temperatures for Buchanan Lake, assuming it would have had the same profiles without destratification. The actual lake temperatures were 1.9 and 1.1°C warmer for the two dates respectively than calculated from the stratified profiles. Therefore, the total heat content of the lake was not greatly changed by destratification and could be accounted for by reduced evaporation of only 1.7 and 1.0 cm of water on the two dates.

<u>Dissolved Oxygen</u> The dissolved oxygen concentrations below 25 feet ranged from 4 to 0 ppm at both stations when destratification was started.

Three weeks earlier low oxygen conditions were only observed below 30 feet. During the first week of mixing the concentration at 30 feet at B-2 rose to 5 ppm and it remained at this value or higher for the rest of the summer except for three results (2, 2 and 3 ppm) in early September.

At station B-1 (Figure C-1b) oxygen wasn't completely restored until the diffuser was moved on August 24. There were rapid decreases in oxygen when the compressor failed prior to September 9th and again after the compressor was turned off on September 23. This indicates a large demand for oxygen which was being satisfied when the lake was being mixed.

The uniform oxygen conditions on October 14 were due to natural mixing but the compressor was running after that time until October 28. Excellent oxygen conditions persisted for the next week until at least November 4th, and this is likely due to currents induced by cooling although there could have also been some reduction in the oxygen demand.

It seems clear that destratification can prevent anoxic conditions and that in Buchanan Lake a large oxygen demand by the sediments was being met. More intensive sampling with the compressor on and off might have given an estimate of the rate of oxygen utilization but the weekly data don't support such a calculation.

Carbon Dioxide The carbon dioxide results are illustrated in Figure C-1C and the average value of the surface 5 and 10 foot samples (photic zone) are given in Figure C-2.

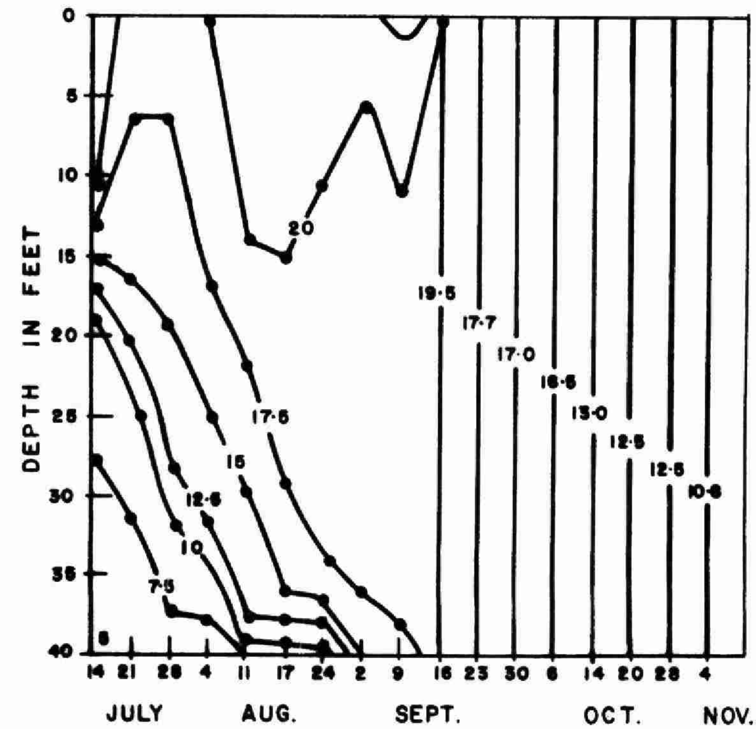


FIGURE C-1a ISOTHERMS B-1

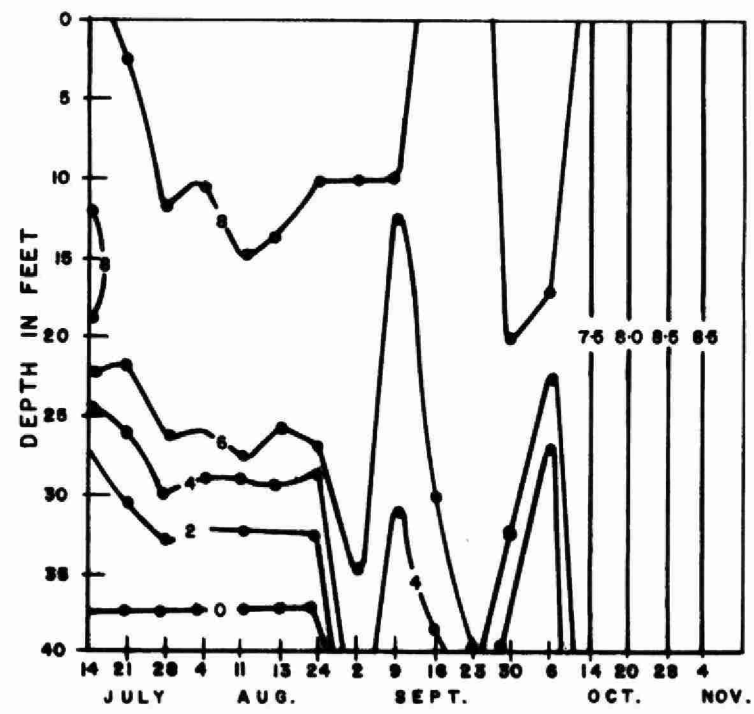


FIGURE C-1b D.O. ISOPLETH B-1

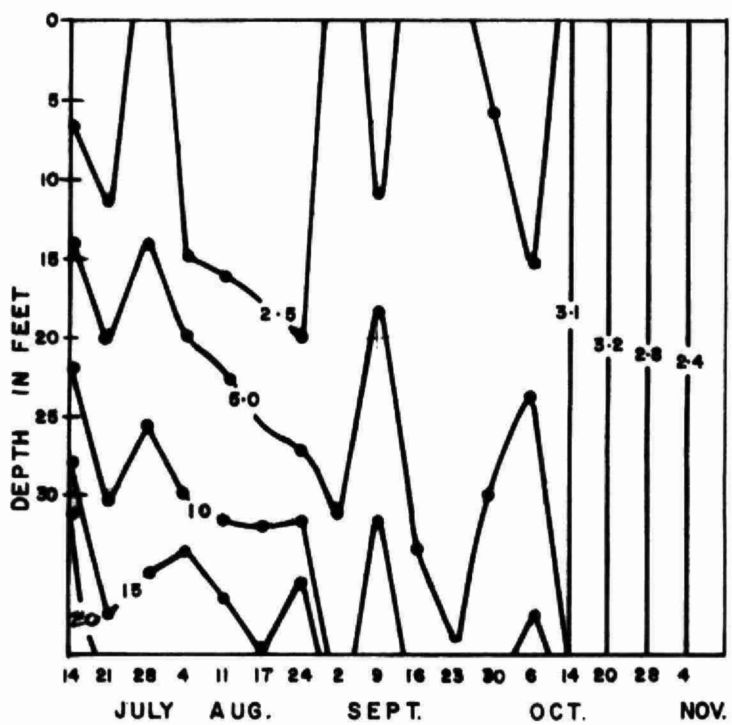


FIGURE C-1c CO_2 ISOPLETH

Figure C-2

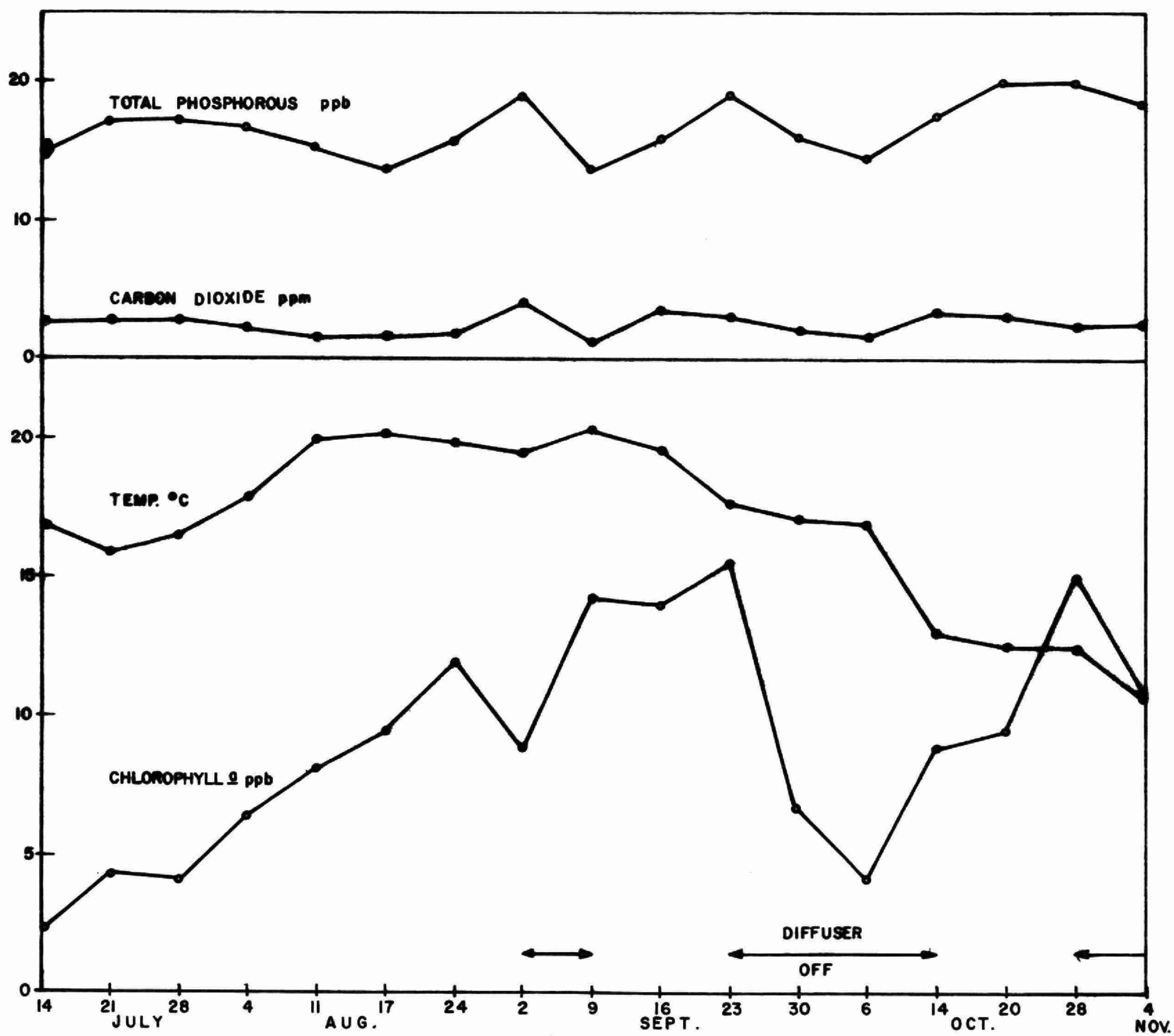
Weekly Averages of Total Phosphorus, Carbon Dioxide Temperature and Chlorophyll a.

Each Total Phosphorus value in parts per billion (ppb) is the mean of all samples collected on a given date weighted according to the volume of water at the corresponding depth.

Carbon Dioxide values are the arithmetic means of the surface five and ten foot samples (photic zone) from both stations expressed as parts per million (ppm) as carbon dioxide.

Temperatures are the means of all measurements weighted according to the corresponding water volume.

Chlorophyll a values are the arithmetic means of the surface, five and ten foot samples (photic zone) from both stations expressed in parts per billion (ppb).



TOTAL PHOSPHOROUS ppb
CARBON DIOXIDE ppm
TEMP. °C
CHLOROPHYLL a ppb
DIFFUSER
OFF
20
10
0
20
15
10
5
0
14
21
28
4
11
17
24
2
9
16
23
30
6
14
20
28
4
JULY
AUG.
SEPT.
OCT.
NOV.

The initial high values in the bottom water were quickly reduced at both stations and there was no particularly noticeable increase in the surface waters.

The concentrations are essentially inversely related to the dissolved oxygen but the mechanical effects of moving the diffuser and stopping the compressor were strikingly similar (graphically) to the effects on dissolved oxygen. The increase in carbon dioxide below 25 feet before September 9 and October 6 when the compressor was not running are in agreement with the dissolved oxygen depletions since carbon dioxide production will deplete oxygen in the absence of a constant supply. The carbon dioxide became evenly distributed during the last four weeks of observations, again agreeing with the oxygen data.

The carbon dioxide being produced by the sediments is swept away by the currents and either lost to the atmosphere or used by algae. Its production only became apparent when the compressor was off and circulation stopped.

The apparent rapid production of carbon dioxide strongly supports the observed decreases in organic matter content of the sediments discussed in the sediment analysis section below.

<u>Minerals</u> The complete major ion composition of the water was determined on the November 4 samples and is given in Table C-1.

The water is quite soft with a higher sulphate concentration than expected.

Conductivity, alkalinity and iron were all higher in the bottom waters on July 14 but the concentrations became uniform within the first few weeks of destratification.

Table C-1

Major Ion Content of Buchanan Lake Water

Ion	Concentration mgm/l
Ca	10
Mg	0.5
Na	1
K	0.6
SO_4	12
Cl	<1
Alkalinity	5
Fe	0.05
Conductivity	31 μmhos

The surface and 40 foot concentrations are summarized in Table C-2 for the pre and post mixed conditions.

Changes in conductivity were readily explained by the variations in alkalinity.

The pH values were always consistent with variations in carbon dioxide - particularly with respect to depth. The surface values ranged from 6.3 to 8.3 over the summer.

The iron, which presumably came from the anoxic sediments via reduction reactions, was greatly reduced in the first week of destratification and became fully uniform at 0.15 ppm within one week after the diffuser was moved on August 24.

Table C-2

Surface and Bottom Concentrations of 6 Parameters

Before and After Destratification

	July 14		September 23	
	Surface	40 feet	40 feet	surface
Fe mgm/l	0.05	1.6	0.20	0.10
Conductivity µmhos	31	40	32	32
Alkalinity mgm/l	6	12	5	5
pH	7.1	6.2	6.7	6.7
Ammonia mgm/l	0.01	0.64	0.07	0.03
Total P mgm/l	0.010	0.042	0.024	0.018

<u>Nitrogen and Phosphorus</u> Nitrite and nitrate concentrations were consistently low with no apparent trends in either one.

Organic nitrogen values (total Kjeldahl nitrogen minus ammonia nitrogen) generally ranged between 0.3 and 0.5 ppm with only a few samples from the 35 and 40 foot depths reaching as high as 0.8 ppm. No trends were apparent with respect to either depth or time and the various changes in duffuser position and operation didn't produce any consistent effects.

Ammonia accumulated in the hypolimnion (see Table C-2) presumably due to decomposition of organic matter in the sediments.

Destratification reduced the ammonia concentration although there was generally slightly more in the bottom water than in the surface which is taken as evidence of constant generation in the sediments. The fate of the ammonia couldn't be explained by changes

in either nitrate or organic nitrogen concentrations. The sediment analysis (see below) suggests some net loss of nitrogen from the lake, however, the overall forces acting on the nitrogen cycle are not clear from either the water or sediment analysis.

Soluble phosphorus concentrations were always less than 0.005 ppm and no trends were apparent.

High phosphorus and iron concentrations in the anoxic hypolimnion on June 24 and July 14 (Table C-2) are taken as evidence that the classical iron-phosphorus recycling mechanism is operating in Buchanan Lake. One prime objective of destratification applied to eutrophication control is to stop this recycling mechanism thus reducing the potential phosphorus supply.

The hypolimnetic concentrations of phosphorus were reduced to less than half of the pre destratification values although the 40 foot samples from B-1 and 30 foot samples from B-2 were slightly higher than the surface value on most sampling dates. This may have been due to some regeneration from the sediments under oxic conditions, however, the sediment analysis did not suggest any decrease in the sediment phosphorus concentration - in contrast to the decrease in organic nitrogen. It is more likely that the phosphorus results for the water were affected by organic debris settling to the bottom since the higher values almost always corresponded to slightly higher organic nitrogen.

The weighted mean total phosphorus concentrations for the lake are plotted in Figure C-2. The high and low results plotted for July 14 are for June 24 and July 14 respectively. The majority of

the results were higher after destratification but never exceeded 0.020 ppm, a concentration not normally associated with nuisance growths of algae. There doesn't seem to be any consistent pattern to the results that can be related to diffuser operating data and in fact most of the variations are probably due to analytical variations at these low concentrations.

Destratification did achieve the objective of controlling the important iron-phosphorus recycling mechanism.

Chlorophyll a The chlorophyll a results were the most unexpected of all. The average values for the surface, 5 and 10 foot samples (photic zone) for both stations combined are plotted in Figure C-2. There was a six fold increase in chlorophyll a concentration between the pre destratification concentration (July 14) and the maximum value on September 23. The increase was steady except for September 2 and there is no explanation for that decrease.

When the diffuser was stopped on September 23 the chlorophyll a concentration dropped sharply although a similar effect was not observed during the breakdown prior to September 9. After the second decrease in concentration observed on October 6, the decision was made to start the diffuser again on October 14 to see if there would be a similar response in the chlorophyll a. Unfortunately this action was confused when the wind fully mixed the lake prior to October 14 and there was an increase in chlorophyll a quite independent of any artificial mixing. However, the chlorophyll a continued to increase for the next two weeks with the compressor running and then fell back by November 4. In any case, the rise in chlorophyll a between Oct. 6 and Oct. 28 would appear to be the result of mixing processes either natural or induced.

While destratification controlled the phosphorus concentration to some extent, it certainly didn't control the algae and in fact all indications are that growth was greater when the lake was being mixed. Perhaps this should not be too surprising since Hooper (1) reported the same result in 1952 following injection of hypolimnetic water to the surface. The algae increased 10 fold by volume and remained for three weeks while the phosphorus returned to pre mixed concentrations within 48 hours.

The chlorophyll a and total phosphorus values in Buchanan Lake prior to destratification were in agreement with the observations for Lake Erie reported by Brydges (13). However, from the second week onward, the amount of chlorophyll a relative to total phosphorus generated points on a chlorophyll a - total phosphorus graph never before reported by any OWRC studies. Conditions returned to "normal" on October 6 when the compressor had been off for two weeks.

Whether 0.015 to 0.020 mgm/l phosphorus will ever produce such high chlorophyll a values in natural waters not being mixed is not known, but it seems quite clear than low phosphorus values can support large algae crops if conditions are right.

It has been pointed out above that both carbon dioxide and ammonia were being generated from the sediments and therefore, because of the rapid circulation rate, the surface water may well have presented a situation of inorganic carbon and nitrogen being in good supply with phosphorus in short supply and the algae grew quite well. Presumably the concentrations in the surface water remained low because they were being used up by the algae as fast as they became available.

While the effects of destratification on algae growth are demonstrated in an empirical way, it would not be advisable to try and draw firm conclusions as to just what was taking place in the lake.

If the algae are in fact utilizing the inorganic carbon then they are in effect working against the process of reclamation by retarding the net loss of carbon from the sediments. This means that winter time mixing would be better since the algae would be at a disadvantage and there might be more loss of carbon dioxide directly to the atmosphere and sediment reclamation would be faster.

It also follows from this reasoning that since there was net loss of carbon from the sediments even with the algae growing, then the nutrient supply is being depleted. Therefore, as the lake sediments improve the algae growth will eventually decline even if mixing is continued. In other words, the algae in Buchanan Lake may have been surviving on a carbon reserve in the sediments which was disappearing at an observable rate.

The increases in algae in oligotrophic Buchanan Lake and reported by Hooper (1) for oligotrophic West Lost Lake are in direct contrast to the decreases observed for eutrophic Kezar Lake (6) and in numerous eutrophic reservoirs (3).

At this point in time, the effects in oligotrophic lakes can't be related to phosphorus concentrations and no such relationship has been reported to explain the effects in eutrophic lakes and reservoirs either.

It is hoped that the results of destratification in highly eutrophic Thompson Lake which is just now being started will shed some light on the contradiction in results.

Sediment Chemistry

The sediments are rich in organic matter which must be largely from leaves and other plant debris washed and blown in from the surrounding forest over the years. The fish kill carried out in 1960 may have contributed a significant amount to the oxygen demand by adding a sudden load of highly degradable material.

As mentioned above, one key objective of the experiment is to sufficiently satisfy the oxygen demand of the sediments so that anoxic conditions will not develop to any serious extent when aeration is finally stopped.

Sampling and Analysis Samples were collected with an Eckman dredge on four dates from stations B-1 (Points A, B, C) and B-2 (Points D, E) (Figure 1) although not a complete set of samples each time. Sediment was taken from the top 2 cm and analysed for total Kjeldahl nitrogen (N), total phosphorus (P), iron (Fe), water content and loss on ignition (LOI) using the methods given by Brydges in a report on sediment analysis in 1970 (14). The chemical oxygen demand (COD) was measured by the routine OWRC method using approximately 1 gm samples of wet sediment. Biochemical oxygen demand (BOD) was measured on a 2 percent solution of wet mud and the results converted to a dry weight basis using the measured water content of the sediment.

Results The analytical data is given in Table S-1, averaged for the number of samples collected on each date. The extra value for station B-1

on September 30th is from point A which had not been previously sampled and had only been oxic for about 3 weeks compared to nearly 10 weeks for the other sampling points.

Table S-1

Sediment Analysis

Results are expressed in mgm/gm dry wt except water content and loss on ignition in percent.

Date	Station	No of Samples	N	P	Fe	% water	% LOI	COD	BOD
July 21	B-1	1	19	1.4	12	96	43.4	750	1
July 28	B-1	1	15	1.4	16	95	43.0	750	4
Aug. 24	B-1	2	15	1.8	13	93	43.5	650	-
Sept. 30	B-1	2	12	1.3	11	92	37.5	585	4
Sept. 30	B-1	1	15	1.5	15	95	45.0	780	6
Aug. 24	B-2	1	15	1.4	12	93	46.0	600	-
Sept. 30	B-2	2	15	1.3	12	93	41.2	710	4

The data does not present a very decisive picture, however, the series of samples from B-1 shows decreases in nitrogen, water content, loss on ignition and COD. All four parameters are inter related (14, 15) so the simultaneous decreases are a strong indication of real change and not just analytical variation. The iron and phosphorus concentrations don't seem to have changed significantly which is expected in the case of aerobic sediments. The BOD results are only approximate due to the large dilution required and to problems with initial rapid oxygen uptake making the true value difficult to determine.

The similarity between the sample from point A and the initial results on July 21 and 28 indicate that the changes are not likely due to scouring of the sediments by the induced water currents. Certainly the current would be as great at point A as anywhere else but the apparent chemical changes were not very large.

The two sets of samples from B-2 are inconclusive since the loss on ignition seems improved, COD is worse and there is no change in the other results.

Further evidence of real improvement in sediment quality at B-1 can be derived from the COD:LOI ratios which are 1.75, 1.77, 1.51 and 1.56 chronologically. This means that the material being oxidized has a greater affect on COD than on loss on ignition. Sulphides and ferrous iron are in this category and both are known from the water chemistry to have decreased over the summer. The COD:LOI ratio for sediments is generally close to 1 (15) particularly for aerobic sediments and the Buchanan sediments seem to be moving in the right direction. These results are consistent with a noticeable decrease over the summer in the tendency for the sediments to produce hydrogen sulphide during storage after collection.

There was a rapid rise in carbon dioxide and ammonia concentrations in the bottom waters following the equipment failure in early September and when the compressor was turned off on Sept. 23rd. Since both come from decomposition in the sediment, the observed changes in the sediment are precisely what would be expected.

The ultimate goal is to have the sediments reach a condition of about 1 mgm/gm N, 6% LOI and less than 80% water content (14, 15).

Linearly extending the observed changes in two months to these final values allows one to speculate as follows on how long aeration will be needed in Buchanan Lake:

Δ N = 1.5 mgm/gm/mo vs 14 needed = 10 mo

Δ LOI = 2.8% /mo vs 37% needed = 13 mo

Δ water = 1.5% /mo vs 13% needed = 9 mo

Therefore, we can expect that a total of one full year forced aeration will "restore" the lake to condition presumably acceptable for fish without further mixing.

Conclusions Results of sediment analysis are quite promising with respect to the objective of improving sediment quality.

The 1972 sampling program will shift more emphasis to sediment sampling and analysis.

Bottom Fauna

Buchanan Lake can't be regarded as a "polluted" lake by any means since there are no human or industrial wastes being added. Therefore, the bottom fauna should be representative of lakes in the area with the anoxic conditions likely the greatest single influence on the population.

Destratification was started relatively late in the year to expect many changes in the bottom fauna but some sampling was done to see if there were any effects and to collect background data for future reference.

Sampling Surface sediment samples were collected on July 1, August 24 and September 30 from each of the six stations shown in Figure 1. One 9x9 Eckman dredge was taken at each station. The macroinvertebrates were separated with a 24 mesh per inch screen (0.65 mm aperture) and preserved in 95% ethanol.

Results The results are given in Table BF-1 according to station and date.

Eight of the 15 samples collected from the five deep stations were void of organisms. All samples collected from two aerobic bags in L. Muskoka as part of a different study contained some macroinvertebrates, therefore, the anoxic conditions in Buchanan Lake probably account for the large number of void samples.

There were no drastic changes observed at the deep stations over the summer but by September 30 there were organisms at four of the five stations compared with only one station with organisms on the first two sampling dates. This change may well be due to the establishment of oxic conditions.

The one station located in shallower water (2C) where some oxygen was probably available gave different results than the other five locations. Prior to aeration this station supported worms, which have very limited mobility, while the other locations (except for a snail at 1 a) had only the more mobile organisms. Also, there seemed to be an increase in midge fly larvae after aeration as well as an increase in the variety of taxa. Perhaps this station because

of its depth and location, was very near to the normal aerobic community for this type of lake so that when conditions improved after aeration, organisms quickly migrated in and a denser and more stable community was established. When recovery depends on the migration of aquatic invertebrates, recovery will be slow unless, 1) the travelling distance is very short or, 2) the lake supports organisms such as amphipods which are readily mobile. In a soft-water lake which supports mostly aquatic stages of dipterons as well as sludge-worms, repopulation by worms may take years and the repopulation of dipterons would largely materialize as a result of egg laying in the summer and fall. Perhaps next summer there will be a dramatic increase in the number of midge larvae in Buchanan Lake (midges were probably too small on September 30 to be retained by the screen).

It is interesting to note that no amphipods appeared, even at station 2C, so that in order to establish this important fish food some form of stocking may be required in the future when a suitable habitat becomes available.

Table BF-1

Bottom Fauna

Station 1a - depth - 12.5 m
- dredge full on all 3 dates
- pine needles in sediment
- brown-black muck

July 1 - 1 midge larva (Pentaneurini)
1 snail (Amnicolidae)
3 mayflies (Stenonema)

Aug. 24 - No organisms

Sept. 30 - 9 midge larvae (Chironomus s.g. Chironomus)
4 mosquitoes (Chaoborus)

Station 1b - depth - 9.0 m
- dredge full on all 3 dates
- pine needles in sediment
- brown-black muck

July 1 - 1 mosquito (Chaoborus)

Aug. 24 - No organisms

Sept. 30 - 1 midge larva (Chironomus s.g. Chironomus)

Station 1c - depth - 11.7 m.
- dredge full on all 3 dates
- pine needles in sediment
- brown-black muck

July 1 - No organisms

Aug. 24 - No organisms

Sept. 30 - No organisms

Station 2a - depth - 8.2 m.
- dredge full on 2 dates, 1/2 full on Sept. 30
- pine needles in sediment
- brown-black muck

July 1 - No organisms

Aug. 24 - No organisms

Sept. 30 - 38 midge larva (Chironomus s.g. Chironomus)
1 mosquito (Chaoborus)

<u>Station 2b</u> - depth 13.1 m.
- dredge full on all 3 dates
- pine needles in sediment
- brown-black muck

July 1 - No organisms

Aug. 24 - 11 midge larvae (*Chironomus* s.g. *Chironomus*)

Sept. 30 - 2 midge larvae (*Chironomus* s.g. *Chironomus*)

<u>Station 2c</u> - depth 5.5 m.
- dredge 1/2 full on first 2 dates and full on Sept. 30
- pine needles in sediment
- brown-black muck

July 1 - 2 midge larvae (*Chironomus* s.g. *Chironomus*)
31 worms (*Limnodrilus hoffmeisteri*)

Aug. 24 - 369 midge larvae
354 *Chironomus* s.g. *Chironomus*
15 *Tanytarsus* ?

3 worms
2 *Limnodrilus hoffmeisteri*
1 *Tubifex*?*tubifex*?

Sept. 30 - 276 midge larvae
264 *Chironomus* s.g. *Chironomus*
6 *Procladius*
3 *Microtendipes*
3 *Tanytarsus* ?

44 worms
42 *Limnodrilus hoffmeisteri*
1 Rhyacodrilus montana
1 *Ilyodrilus templetoni*

Conclusions

While the limited results may be seriously affected by normal sampling variation they at least showed improvement rather than a deterioration in the bottom fauna population.

The 1972 sampling program should be extensive enough in time and space to clearly define the changes in bottom fauna.

Velocity Measurements

Vertical velocities were measured in the region of the air bubbles at the water surface to determine the vertical flow induced by the bubbler. These measurements were conducted both while the bubbler was operating and approximately one hour after the bubbler had been turned off. The mean vertical velocities and vertical turbulence intensities were evaluated at numerous locations in the vicinity of the bubbles with a hot film anemometer (accurate to less than 1.0 cm/sec). Determinations of the total vertical water movement from the measured velocities were necessarily estimates as the locations of the measurements relative to the air bubbles was approximate. This resulted from visible changes in the position of the bubbles at the surface relative to the shoreline and the difficulty of obtaining precise location fixes from a virgin shoreline which has not been mapped in detail. In addition, the velocity measurements themselves are estimates. As the measurements were made from a small boat, they include vertical boat motion caused by waves, movement of personnel and vibrations induced by the operation of an onboard portable electrical generator. An estimate of these effects was obtained by measuring vertical velocity near the centre of the lake one hour after the bubbler had been turned off. This estimate of other effects was subtracted from the measurements obtained near the bubbles.

Results The diffuser produced two regions of bubbles at the water surface referred to as large and small bubble zones, due to the change in port size in the diffuser. The relative sizes of the regions appear

in Figure V-1. The dimensions of the regions are approximations determined by field measurements which compare reasonably well with the port configuration of the bubbler diffuser pipe. Some differences are expected due to misdrilling of ports, partially blocked ports or misalignment of the diffuser line. The vertical velocity measurements appear in Table V-1 for the locations in Figure V-1. It is immediately apparent that the bubbler generates mean vertical velocities an order of magnitude greater than those occurring naturally but the vertical transport is limited to an area close to the point where the bubbles reach the surface. A vertical velocity of approximately 30 cm/sec was recorded at the centre of the large bubbles, which is extremely large when compared to normal occurring vertical transport of less than 1 cm/sec. Similarly turbulence intensities of approximately 30 percent were recorded in the region of intense bubbling activity. This value (which is indicative of an intense mixing process) is far in excess of naturally occurring turbulence intensities of 5 to 10 percent in the surface layers.

Volume flows were computed from the velocity measurements in two ways. A vertical flow of 52.1m^3/sec (1840 cfs) is obtained by assuming linear velocity variations between the locations in Figure 1 and summing the flow in each element. It is unlikely that the assumption of linear variation is valid particularly for the zero velocity measurements which are probably outside the vertical rising section. If the flow is considered to be confined to a region approximately 1.5 meters on either side of the bubble centre line and the velocities

Figure V-1   Velocity Survey August 20, 1971

All dimensions are approximate and not to scale

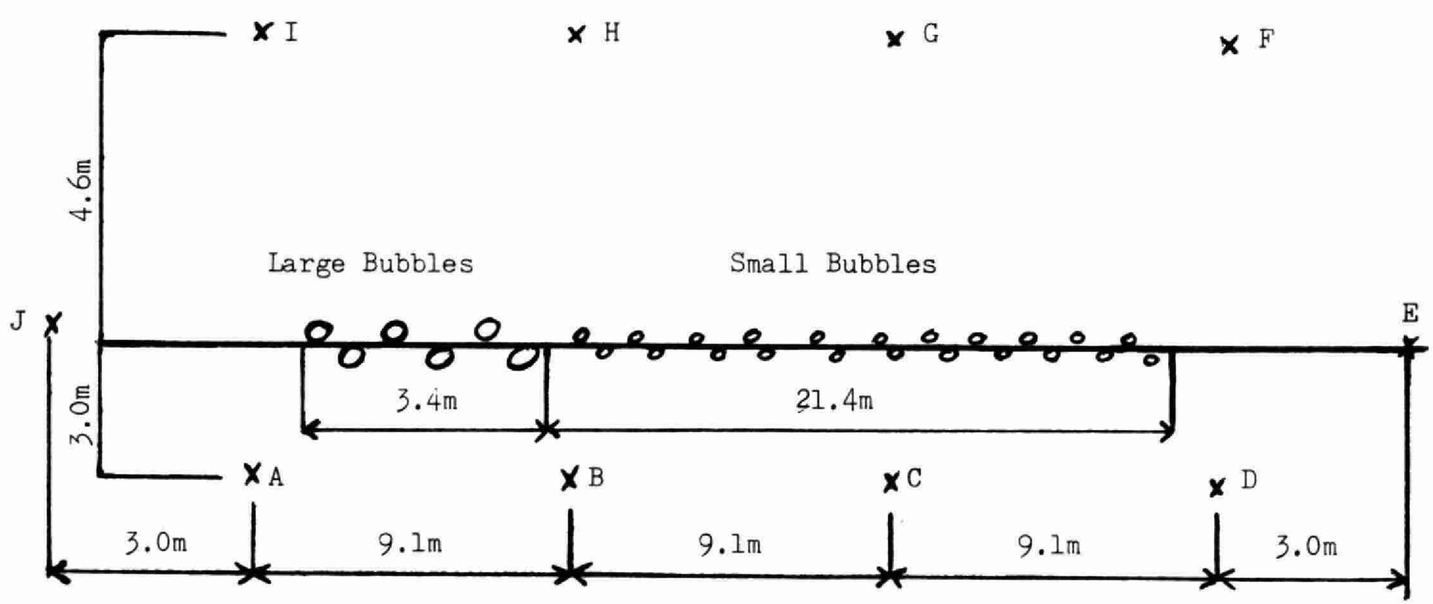


TABLE V-1

Velocity Measurements

August 20, 1971

Location	Vertical Velocity (perpendicular to the water surface)		Vertical Turbulence Intensity Percent
	Compressor on - cm/sec	Compressor off - cm/sec	
A	12.2		5
B	7.3	0.0	16
C	0.0	1.0	
D	0.0		
E	0.0		
F	1.8		
G	0.0		
H	2.4	0.0	
I	0.0		
J	0.0		
Centre small bubbles	9.1		27
Between small and large bubbles	16.7	1.0	17
Centre large bubbles	33.4		29

taken within the bubble zone assumed valid, a vertical flow of $26.8 m^3/sec$ is obtained (945 cfs).

An estimate of 25 to $50 m^3/sec$ induced vertical flow from the bubbler is considered reasonable based on the field measurements of August 20. The large turbulence intensity measurements would indicate that the effective mixing would probably be closer to the higher velocity range as turbulence would augment the effect of the mean velocity transport by large eddy entrainment.

Based on the $25 m^3/sec$ estimate, a volume of water equal to the entire lake volume is displaced every 4.8 hours.

The vertical kinetic energy of the water is estimated to be from 0.2 to 0.4 horse power which compares quite favourably to the energy being applied by the compressor which has a 2 horse power maximum.

Recommendations The experiment was carried out on a rule of thumb basis with the result that most measurements were either approximate or hampered by difficulty of execution. Some of these problems could be alleviated by the following:

1. carry out some laboratory tank tests of fixed pipe diffusers with different port configuration to determine an optimum design.
2. conduct a limited dye injection study injecting dye at the bottom near the diffuser to trace the water area affected by the bubbler.
3. establish permanent fixed spar buoys in the area of the diffuser bubbles to provide a frame of reference.
4. utilize the spars as support facilities for the velocity measuring equipment.

Fishery

The fishery has not received extensive attention during these early stages of destratification even though the ultimate objective is to restore an acceptable sport fishery. It is more important initially to determine if there is a potential for fish production.

Stocking with over 9000 trout over a ten year period had not produced good fishing and the exact population at the start of the destratification experiment was not known. About 100 rainbow trout had been put in the lake in March, 1971.

On September 21, gill nets were set by the Department of Lands and Forests. They were placed to a depth of 6 feet and left for 24 hours. This was done only to see what kinds of fish were present and what condition they were in - not to determine the population size. The results are given in Table F-1.

Table F-1

Fish taken with gill nets on Sept. 21

1 rainbow trout	1 year old	21 oz.	15.1 inches
3 speckled trout		7 oz.	10.2, 10.6 & 11.5 in.
2 lake chub			
1 bullhead			

The trout were apparently healthy and had grown well.

It seems as if the habitat provided by destratification was amenable to trout and it now felt that a limited stocking of trout would be in order for the spring of 1972.

Zooplankton

Quantitative Aspects Figures Z-1 and Z-2 depict the changes in the standing stock of zooplankton in Buchanan Lake for the period July 14 to November 4, 1971. As indicated in Figures Z-1 (a) and Z-2, a substantial increase in zooplankton numbers in the pelagic zone of the lake occurred following destratification. A comparison of zooplankton numbers in the pelagic zone with those of the entire lake is depicted in Figures Z-1a and b. Figure Z-1b was derived using volumetric factors, representing the relative proportion of each water strata to another. As indicated, a similar pattern of increase was apparent in the water column representing the pelagic zone and in the entire water volume. Although the most significant increases occurred in the deeper portions of the lake (Fig. Z-3) it was actually the moderate rises in zooplankton numbers in the surface waters which were responsible for the overall increases in the entire lake, owing to the fact that the surface waters account for a much larger proportion of the total water volume than do the deeper strata.

Qualitative Aspects Table Z-1 provides a breakdown in the species composition for the sampling period.

Copepoda Maximum numbers of calanoids (exclusively *Diaptomus minutus*) occurred between mid-July and the end of August. By mid-autumn only late copepods were abundant, as indicated by the relatively low numbers of nauplii larvae. Additionally, *Epischura lacustris*, was encountered, in relatively low numbers, demonstrating a similar pattern in seasonal development.

Tropocyclops prasinus mexicanus was the dominant cyclopoid in the lake, and was characterized by a general increase throughout

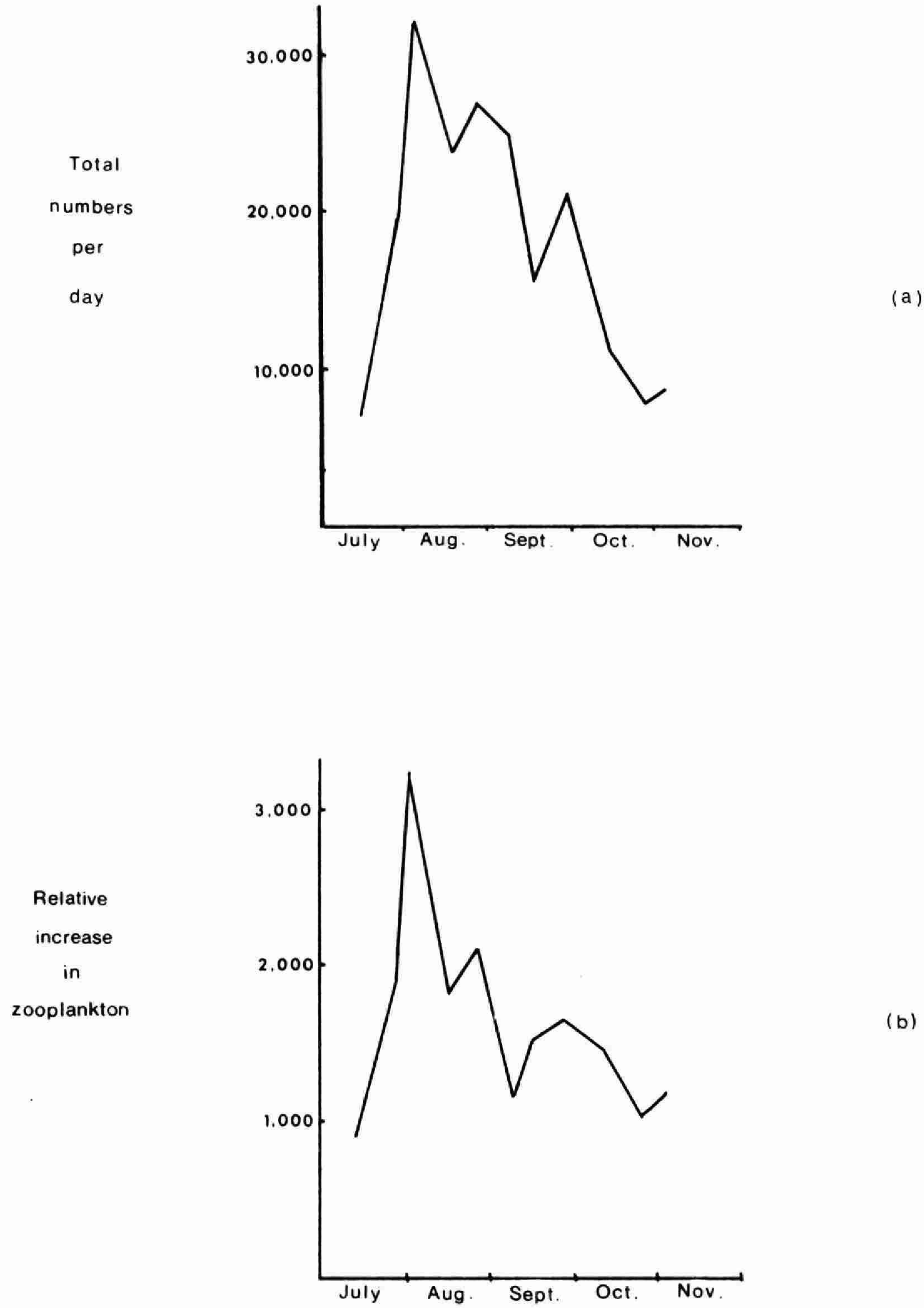


Figure Z-1. (a) Seasonal changes in zooplankton abundance in Buchanan Lake from July 14 to November 4, 1971 representative of a 22.86 sq. cm. column in the pelagic zone of the lake.

(b) Relative increase in biomass (zooplankton) for Buchanan Lake from July 14 to November 4, 1971, computed using volume-factors.

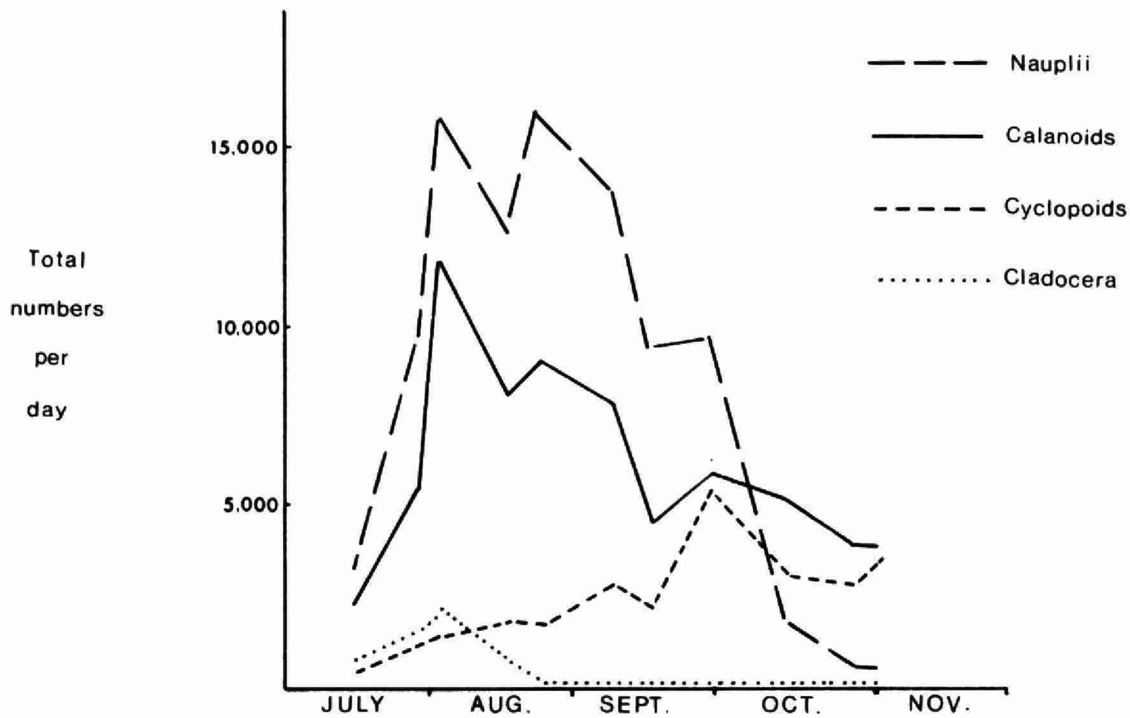


Figure2-2. Seasonal changes in the abundance of planktonic crustaceans in Buchanan Lake, for a 22.86 sq.cm. column in the pelagic zone, for the sampling period, July 14 to November 4, 1971.

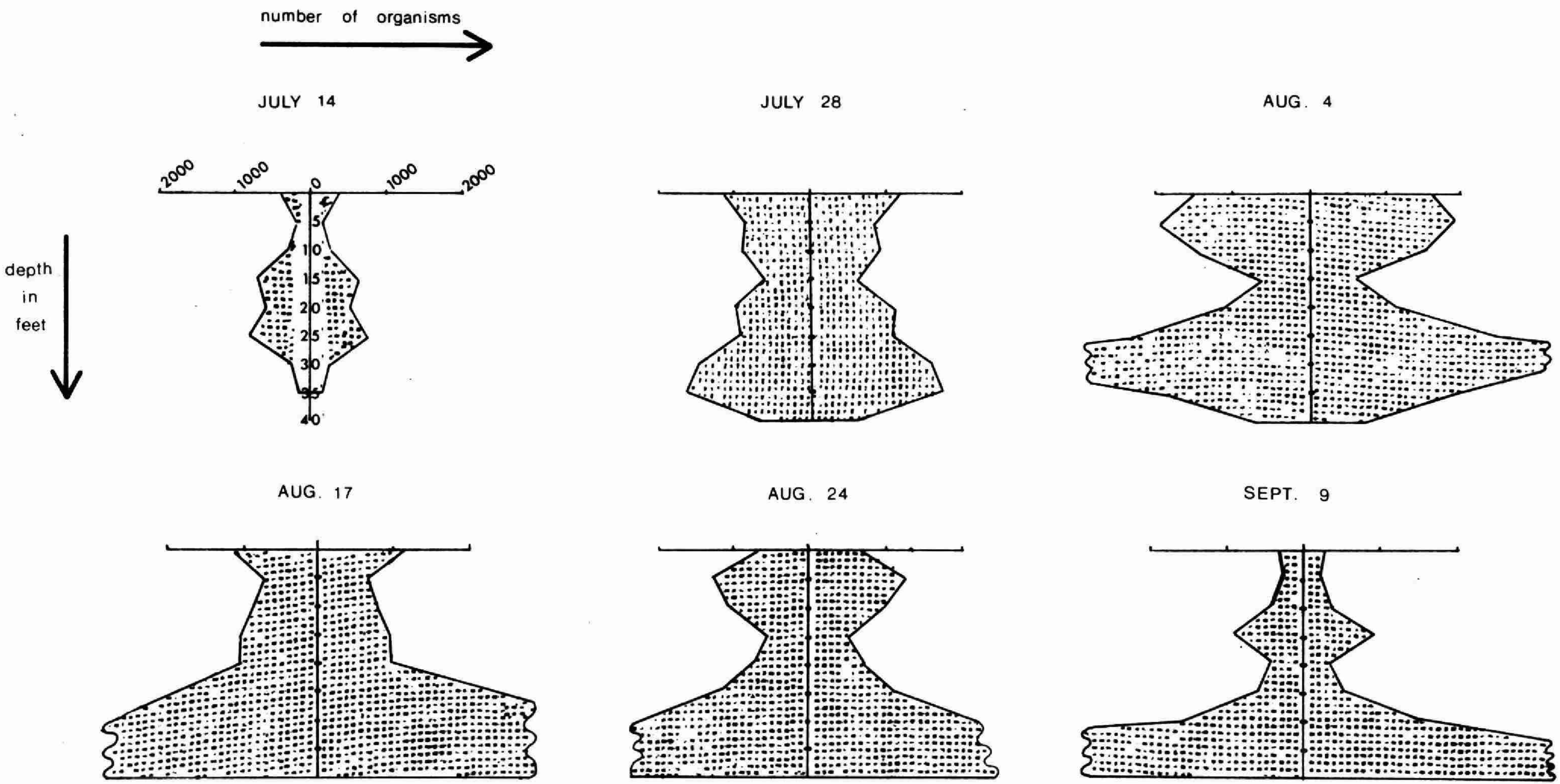


Figure 2-3. Total number of organisms (zooplankton) per trap* at five foot intervals in Buchanan Lake for the sampling period July 14 to September 9, 1971.

* volume of trap = 19.91 litres

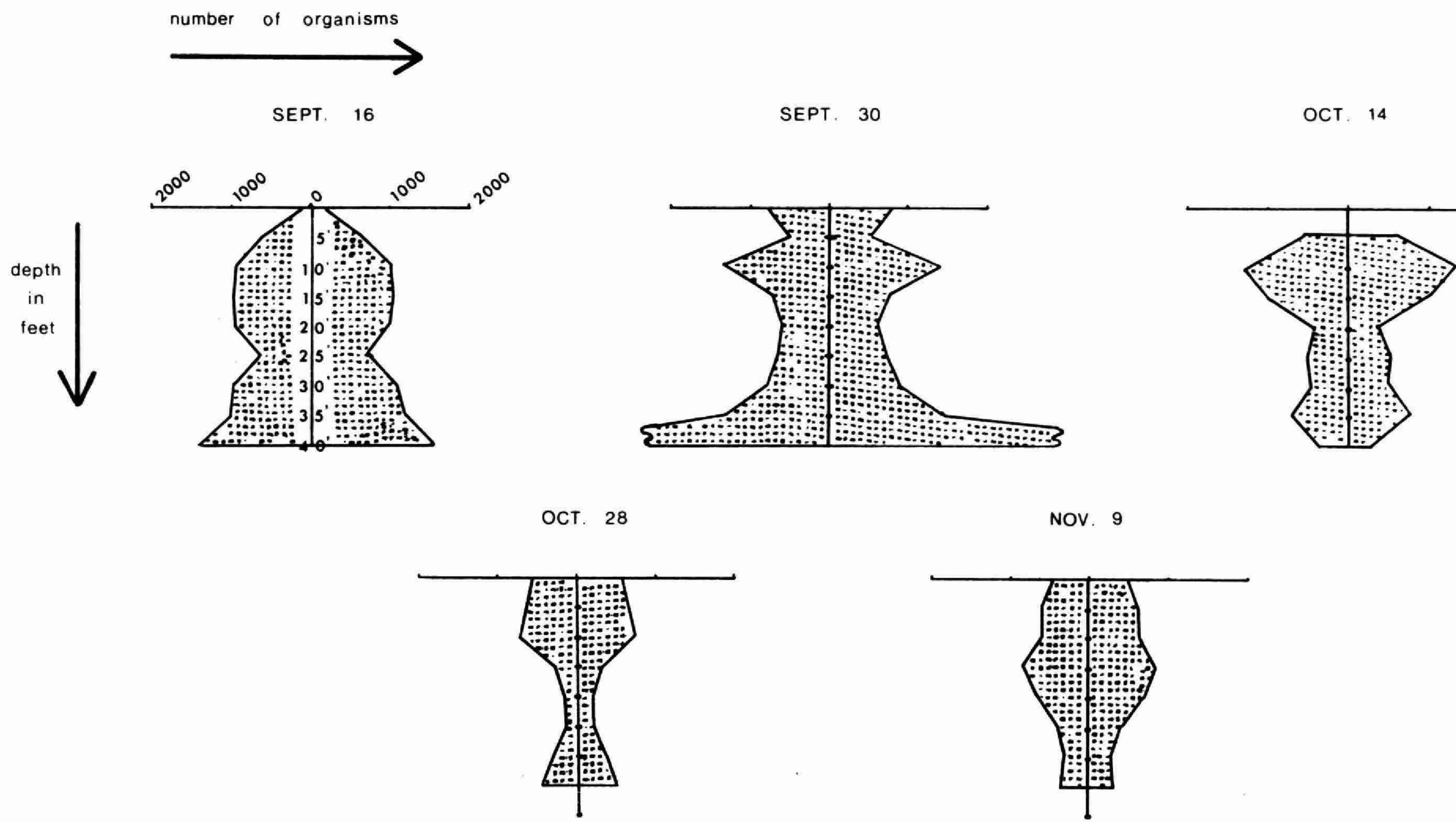


Figure 2-3 (Cont'd) Total number of zooplankton per trap at five foot intervals in Buchanan Lake for the period September 16 to November 4, 1971.

the experiment. Cyclops scutifer occurred in moderate numbers early in the sampling period and showed a distinct preference for the deeper waters. Eucyclops agilis and Orthocyclops modestus were occasionally encountered.

Cladocera Cladocerans never dominated the crustacea of the lake. Holopedium gibberum, gibbecum, diaphanosoma leuchtenbergianum, Daphnia catawba and Bosmina spp. were the most common. Holopedium gibberum did achieve some prominance from mid-July through mid-August.

Table Z-1

Percentage composition of species in Buchanan Lake for the sampling period July 14 to October 28, 1971 (taken as an average of the nine sampling depths)

SPECIES	% Composition
nauplius larvae	49.3
calanoid copepodids (exclusively Diaptomus minutus)	34.6
cyclopoid copepodids	12.8
(Tropocyclops prasinus mexicanus) *	
Cyclops scutifer	
Eucyclops agilis	
Orthocyclops modestus	
Cladocera	
Holopedium gibberum *	3.3
Diaphanosoma leuchtenbergianum	
Daphnia catawba	
Daphnia sp.	
Bosmina sp.	
Ceriodaphnia sp.	

* indicates the dominant species

Discussion Zooplankton form a critical link in the aquatic food chain. Planktonic crustaceans feed on the fine particles - algae, bacteria, detritus - suspended in the surrounding medium. In turn, zooplankton are fed upon by most freshwater fish, although other food reserves may be utilized. For example, various species of trout of the genera Salmo and Salvelinus feed on Daphnia over 1.2 mm, and in their absence utilize a nonplanktonic food source such as small fish or benthic invertebrates (16).

Hazelwood and Parker (17) noted that the density of Diaptomus was well correlated with oxygen. The authors observed that numbers of Diaptomus were dramatically reduced below oxygen concentrations of 2.2 ppm. Above 2.2 ppm Diaptomus flourished. Results from our study demonstrated that D minutus, as well as cyclopoids, increased in the bottom waters following oxygen replenishment. Fig. Z-3. Oxygen replenishment, through physical aeration and photosynthetic activity, in the deeper waters of the lake has undoubtedly acted as a capacity factor, increasing the total volume of suitable environment available for population growth. This would be complemented by corresponding increases in viable phytoplankton concentrations in the lake.

It is well recognized that the interpretation of natural changes in species composition and seasonal dynamics are difficult due to natural variation. It is unfortunate that samples were not collected in previous years or earlier in the year to document the natural succession of zooplankton populations in Buchanan Lake. Such information would have

provided excellent background material so that a meaningful comparison of induced changes could be made. However, it is our contention from an assessment of the available data that the development of the relatively high standing stocks of zooplankton in Buchanan Lake was effected following induced aeration and the associated biological and chemical changes.

Phytoplankton Communities

Results and Discussion Standing stocks of phytoplankton (measured by the areal standard unit method, a.s.u.) increased approximately five times between July 14 and September 23 when the maximum crop was recorded (Figure P-1). The a.s.u. increase was not as uniform as that measured by chlorophyll a concentrations (Figure P-1), although maximum a.s.u. and chlorophyll a levels were both attained on September 23.

Considering the quantitative and qualitative aspects of phytoplankton communities, three main periods of development were apparent and are summarized below.

Phase 1 A definite pattern in the vertical distribution of standing stocks was observed during the pre-operational phase of the experiment. Algal numbers were low to moderate in the epilimnion and in the lower hypolimnetic waters and moderately high in the lower metalimnion and upper hypolimnion (Figure P-2a). Qualitatively, changes in dominating species were apparent with depth. For example, the surface waters were dominated by the diatom *Cyclotella* and the chrysophyte *Synura*, whereas in the upper portion of the metalimnion the most important alga was the blue-green *Merismopedia*. The lower thermocline and upper hypolimnion-strata

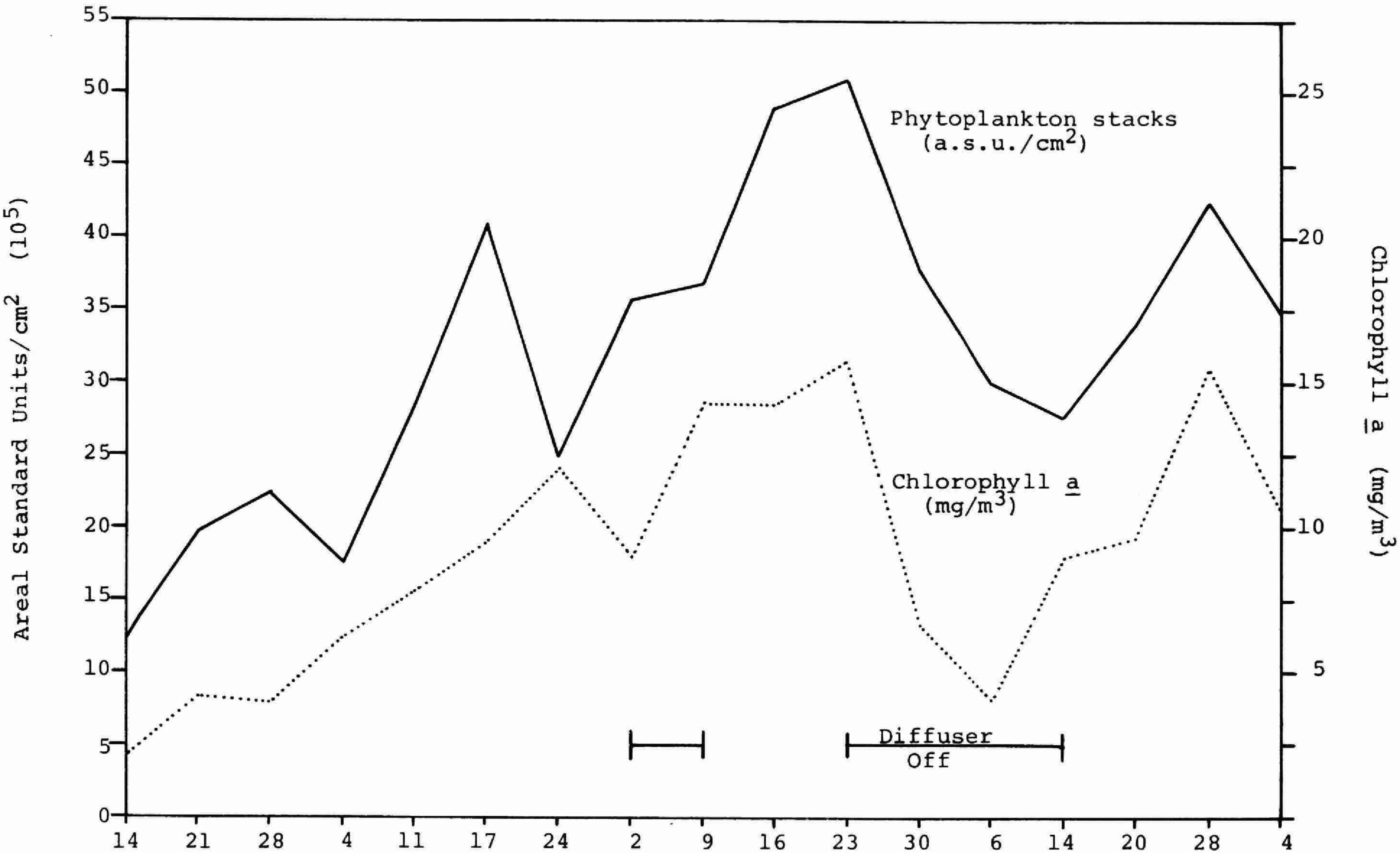


Figure P-1 Standing stocks of phytoplankton in the pelagic zone (Station B-1) of Buchanan Lake, July 14 - November 4, 1971. Solid line depicts algal stocks as areal standard units/cm^2 (i.e. surface to bottom) while the broken line indicates chlorophyll a concentrations computed as the arithmetic mean of the surface, 5 and 10 foot depths (i.e. euphotic zone).

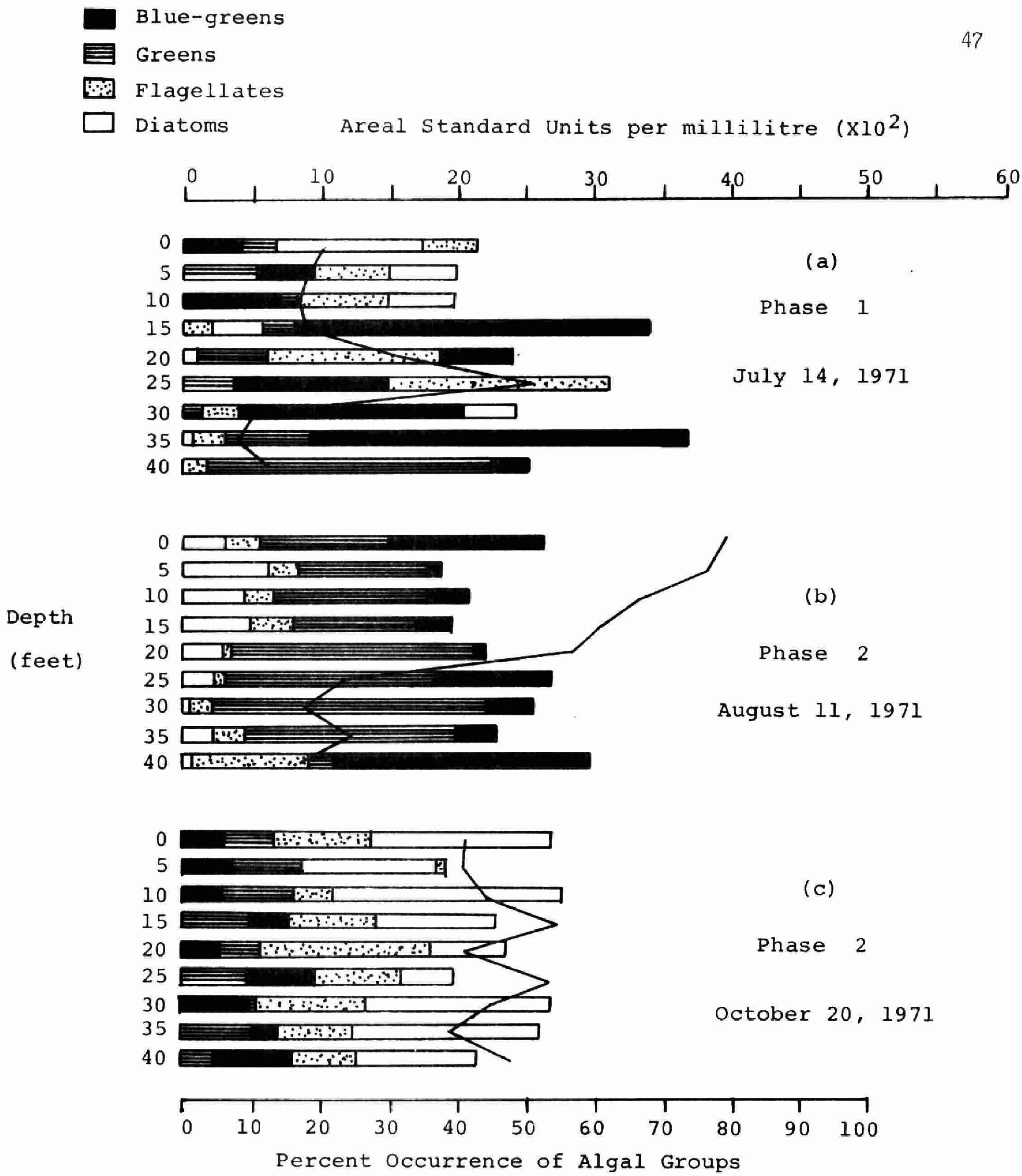


Figure P-2 Standing stocks of phytoplankton in Buchanan Lake (Station B-1) on July 14, August 11 and October 20, 1971. Solid line indicates total a.s.u. per ml in the water column (surface to bottom) while the bar graph represents the percent occurrence of the four main algal groups at each depth. For example, the sample collected from 10 feet on July 14 (Phase 1) had a total a.s.u. value of 850; 14% of the total algae were blue-greens, 17% were greens. 30% were flagellates and 39% were diatoms.

where maximum numbers of algae were found contained high numbers of chrysophytes including Synura and Dinobryon. The deeper zones of the lakes were populated almost exclusively by the blue-green Aphanothece and the green alga Sphaerocystis.

Based on the vertical distribution of algae and species composition, pre-operational Buchanan Lake was typical of many small Precambrian lakes (18, 19, 20, 21, 22). Schindler and Holmgren (22) would undoubtedly include Buchanan Lake in their Class B scheme for typifying lakes; "small, deep, protected lakes, with the euphotic zone extending into a shallow, relatively rich hypolimnion...one or more pronounced cell maxima below the thermocline...the metalimnetic maxima usually consists of the Chrysophytes Dinobryon spp. and Ochromonas spp". A curious feature of such lakes is that significant numbers of healthy algal cells can be found at or below the compensation point. The low water temperatures and more favourable nutrient regimes (phosphorus, nitrogen and free CO_2) characterizing such strata probably allow the high algal populations "...either to maintain themselves or to increase, even though adequate light may be limited to infrequent occasions" (18, 20, 22). With specific reference to Buchanan Lake, the presence of relatively high numbers of Dinobryon, Synura, Sphaerocystis and Aphanothece at the limit of or below the euphotic zone indicates that an enriched hypolimnion was effectively stimulating biomass production at low light intensities.

Phase 2 The second phase in phytoplankton development began on July 15 and continued until September 23 when the maximum stock was attained, and was most certainly a direct consequence of destratification (Figure P-2b). Extremely high algal numbers characterized the upper waters of the lake on all sampling occasions; a gradual decrease with depth in a.s.u. values was apparent (Figure P-2b). The flora at all depth was dominated by

Aphanothece and *Merismopedia*. Green or chlorophycean algae including *Ankistrodesmus*, *Tetraedron*, *Sphaerocystis*, *Oocystis* and *Arthrodesmus* were relatively abundant in the lake. The consistent appearance of high numbers of Chlorophyceae is rather uncommon in unpolluted Precambrian lakes (20, 22); in fact such species are most often associated with enriched waters (23, 24, 25).

Phase 3 The third and final phase of phytoplankton growth occurred between September 23 and November 4. As indicated earlier, the diffuser was stopped on September 23. Subsequently, a.s.u. values as well as chlorophyll *a* concentrations decreased rapidly (although a similar effect was not observed following a mechanical breakdown on September 9). It should be stressed that phytoplankton numbers never decreased to pre-destratification levels (Figure P-2c). Following the diffuser start-up on October 14, a.s.u. values gradually increased until October 28. This second algal maximum cannot be attributed solely to induced mixing as wind and wave activities mixed the lake between October 7 and October 14. Additionally, the pleasant weather conditions uncommon to many Octobers in Ontario may have been instrumental in promoting the unusually high algal numbers. In summary, it is likely that the algal growth detected during the latter part of October was affected by both natural and induced mixing.

During the third phase a.s.u. values were generally uniform with depth (Figure P-2c) and samples of all strata were dominated exclusively by the diatoms *Cyclotella* and *Rhizosolenia*. As in the second phase, relatively high numbers of green algae including *Ankistrodesmus*

Chlamydomonas, Sphaerocystis, Tetraedron and Arthrodesmus were encountered at all depths.

It appears conclusive from both chlorophyll a and a.s.u. data that induced destratification initially increased algal biomass in Buchanan Lake and that relatively low phosphorus concentrations apparently supported the exceptionally high algal stocks - up to 5,800 a.s.u. per ml. As pointed out above, mixing caused continuous injection into the surface waters of ammonia and carbon dioxide from the sediments and may have compensated the algae for the apparent short supply of phosphorus. Whether such a situation would ever occur in a lake not being mixed isn't known.

The presence of high numbers of green algae seems consistent with the nutrient conditions. Provasoli (25) found that maintaining inorganic nitrogen concentrations in frequently fertilized fish ponds in Israel promoted growth of green algae and that blue-green algae failed to develop. It is possible that the high numbers of Chlorophyceae in Buchanan Lake were maintained by the continuous generation and subsequent circulation of free ammonia from the sediments into the overlying water.

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